Hydrodynamical Simulations of the Uranian Rings

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We investigate the global dynamics of the Uranian rings using a modified 2-D smoothed particle hydrodynamic code combined with a 2-D tree code used to compute the particle-to-particle gravitational interactions. This code includes epicyclic fluid motion, non-axisymmetric flow, local and non-local shear viscocity, self-consistent scale height evolution, ring-satellites gravitational interaction and co-evolution, and ring self-gravity. To follow the scale height of each particle we solve the vertical momentum equation for the flow using a Runge-Kutta scheme with a second order polynomial fit to the vertical behavior of the fluid pressure (Borderies, Goldreich, and Tremaine 1985. *Icarus*, **63**, 406). The behavior of the fluid viscosity is obtained from Mosqueira (1996. *Icarus*, **122**, 128) who found good agreement between an extension to the non-local viscosity model of Borderies, Goldreich, and Tremaine (1985) that includes local terms with the results of a local patch-code ring simulation. Our present viscosity model incorporates further terms which account for the epicyclic limit to the mean free path (Goldreich and Tremaine 1978. *Icarus*, **34**, 227). This treatment covers both the high and low ring density regimes. Our approach treats the fluid work terms and internal energy self-consistently even in the presence of a non-zero divergence of the fluid velocity. Even within a 2-D framework the Uranian rings are so thin compared to their semi-major axes that radial resolution requires too many particles given our present computer resources. To address this issue we have developed a physical scaling that reduces the semi-major axis of the ring while preserving its width and, we believe, retains the relevant global satellite-ring dynamics. With a conservative value of the scaling parameter that reduces the ring's semi-major axis by a factor of 10, our scaling allows for savings between a factor of 20 in the case of synodic time scales, a factor of 200 for shear timescales, and a factor of 2000 for viscous timescales. In the present study we use this scaling to test the validity of the self-gravity model of eccentric ring precession (Goldreich and Tremaine 1979. *Astron. J.*, **84**, 1638).

Abstract submitted for 1996 DPS meeting

Date submitted: LPI electronic form version 5/96